Leonard Kleinrock, *UCLA* and *Nomadix Inc.*

Nomadic Computing and Smart Spaces

It is amazingly difficult to predict the shape of the Internet over the next 10 years. Focusing on some specific technologies, however, I can state with considerable certainty the direction they will take.

Currently, most users think of their computers as associated with their desktop appliances or with a server located in a dungeon in some mysterious basement. However, many of those same users can be considered *nomads*, in that they carry computers and communication devices with them in their travels between office, home, airport, hotel, automobile, and so on. Moreover, even without *portable* computers or communications, there are many who travel to numerous locations in their business and personal lives, and who require access to Internet services when they arrive at their destinations. Indeed, a move from one's desk to a conference table in one's office constitutes a nomadic move since the computing platforms and communications capability may be considerably different at the two locations.

Access to the Internet is necessary not only from one's "home base," but also while in transit and after reaching one's destination.

Equitable Services for Nomads

The variety of portable *computers* is impressive—from laptop computers to notebook computers, personal digital assistants, smart credit card devices, wristwatch computers, and beyond. In addition, the *communication* capability of these portable computers is advancing at a dramatic pace from high-speed modems to PCMCIA modems, e-mail receivers on a card, spread-spectrum handheld radios, CDPD transceivers, portable GPS receivers, and gigabit satellite access. The combination of portable computing with portable communications is changing the way we think about information processing. We now recognize that access to the Internet is necessary not only from one's "home base," but also while in transit and after reaching one's destination.

In the office, users have three wonderful resources that collectively allow them to access Internet services:

- a high-performance workstation (such as a laptop computer),
- high-speed access to the Internet (via 10/100/1000 Ethernet, for example), and
- a network administrator who makes all of it work for them (installs new hardware and software, manages configuration settings, and so on).

However, as soon as the user leaves the office, he or she leaves behind the last two of these resources and can no longer easily access Internet services. One might argue, correctly, that the Internet is "everywhere"—so why is there a problem? The answer is that the user's laptop appears as an unacceptable alien in the new environment to which it has arrived, and the third resource (the network administrator) is not present to configure the laptop to make it acceptable. Indeed, a major nomadic computing issue that must yet be faced is how to provide the same set of Internet services to the nomad no matter where he or she moves.

A number of capabilities must be put in place to support this new paradigm of "nomadicity." Among these, we can include independence of location, motion, platform, and—with widespread presence—of access to remote files, systems, and services. Essentially, one seeks to provide the illusion of connectivity even when the nomad is disconnected and to provide seamless access to Internet services wherever the nomad travels. To achieve this, not only must the infrastructure be enhanced to provide these capabilities, but applications must become nomadically enabled as well. Currently, most applications

fail in the face of dramatic changes in connectivity, latency, delay, or operational immediacy. Nomadically enabled applications should recognize such eventualities as "the normal case" and be able to provide Internet services anywhere and anytime.

Leaving the Netherworld of Cyberspace

These ideas form the essence of the major shift to nomadic computing. But nomadic computing is merely the first step of the vision I foresee. The next step will take us out of the netherworld of cyberspace and into the physical world of smart spaces. What I mean is that our environments will come alive with embedded technology, so that no longer will I see Internet services as coming to me from the screen on my computer, but rather those services will be embedded in my environment. The walls of my office, my desk, my eyeglasses, my wristwatch, my belt, my automobile, and my refrigerator will contain logic, memory, processing power, cameras, microphones, speakers, displays, actuators, sensors, and more.

When I walk into a room, the room will know that I have entered. I will be able to ask the room in natural language for information on a given subject, and four books will reply with their tables of contents (perhaps one will inform me that it is located in my colleague's office) while the Web presents me with links and information via audio, video, images, holograms, and so on.

Essentially, what I envision with regard to this future of smart spaces is that Internet services will be available to me then just as electricity appears to me now, namely: everywhere, always on, easily accessible, and, most of all, invisible! This notion of invisibility is crucial to the continued growth and penetration of Internet services. ■

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Internet-Based Collaboration in 2010

Imagine a common scene: A small group of people from different organizations meets and decides to engage in a cooperative project. These might be people working on a business deal, people sharing technical information, or a social group planning a future function. They decide to use the Internet to facilitate their interaction. What technology are they likely to use? E-mail is certainly available, but there is currently little else. The only other widely used collaboration technologies are AIM (AOL's Instant Messenger service) and ICQ, which are quite useful but primarily for short interactions. They provide no tools for recording the interaction or connecting the communication with the users' other files.

After 30 years of vigorous technical developments and an explosive adoption of technology, this strikes me as embarrassing. Fortunately, coming developments will trigger dramatic changes in collaboration technology and systems.

The Technical Drivers

I write as 1999 ends, and I see five technical developments that are laying the foundation for a radically different future for Internet-based collaboration.

Security. Control of access to the information is vital to collaboration over the Internet. Throughout the Internet's history, government controls and patent restrictions have limited the adoption of high-quality, fine-grained, security mechanisms. The patent on the most important of the cryptographic algo-